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Kroening

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(54) **(M+1)-FOR-M FERRITE REDUNDANCY SWITCH AND SWITCH SYSTEM**

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H01P 1/383	(2006.01)
H01P 1/36	(2006.01)

(52) **U.S. Cl.**
CPC ***H01P 1/383*** (2013.01); ***H01P 1/36*** (2013.01); ***H01P 1/39*** (2013.01)

(58) **Field of Classification Search**
CPC H01P 1/36; H01P 1/38; H01P 1/383; H01P 1/387; H01P 1/39
USPC 333/1.1, 24.2
See application file for complete search history.

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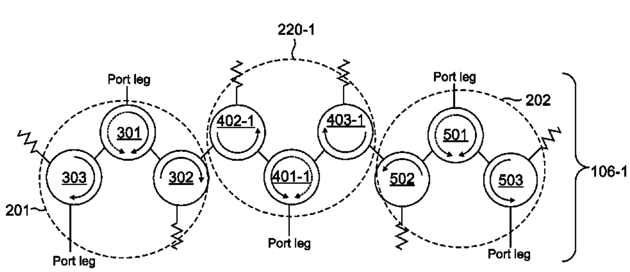
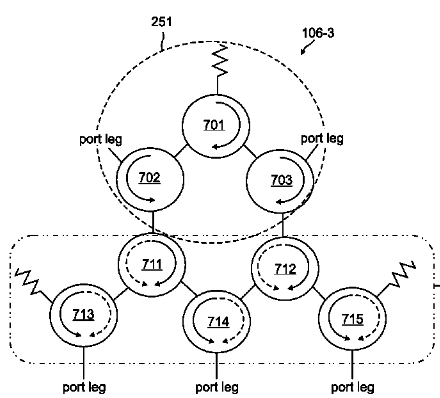
(57) **ABSTRACT**

An (M+1)-for-M redundant switch, where M is an integer greater than 1, is provided. The (M+1)-for-M redundant switch includes a first switch-triad-assembly including a first switching element circulator and two element isolators; a second switch-triad-assembly including a second switching element circulator and two element isolators and; and at least one inverted-switch-triad-assembly including a third switching element circulator and two element isolators. One of the element isolators of the first switch-triad-assembly is arranged to couple power with one of the two element isolators of one of the at least one inverted-switch-triad-assembly. One of the element isolators of the second switch-triad-assembly is arranged to couple power with another one of the two element isolators of one of the at least one inverted-switch-triad-assembly.

20 Claims, 10 Drawing Sheets





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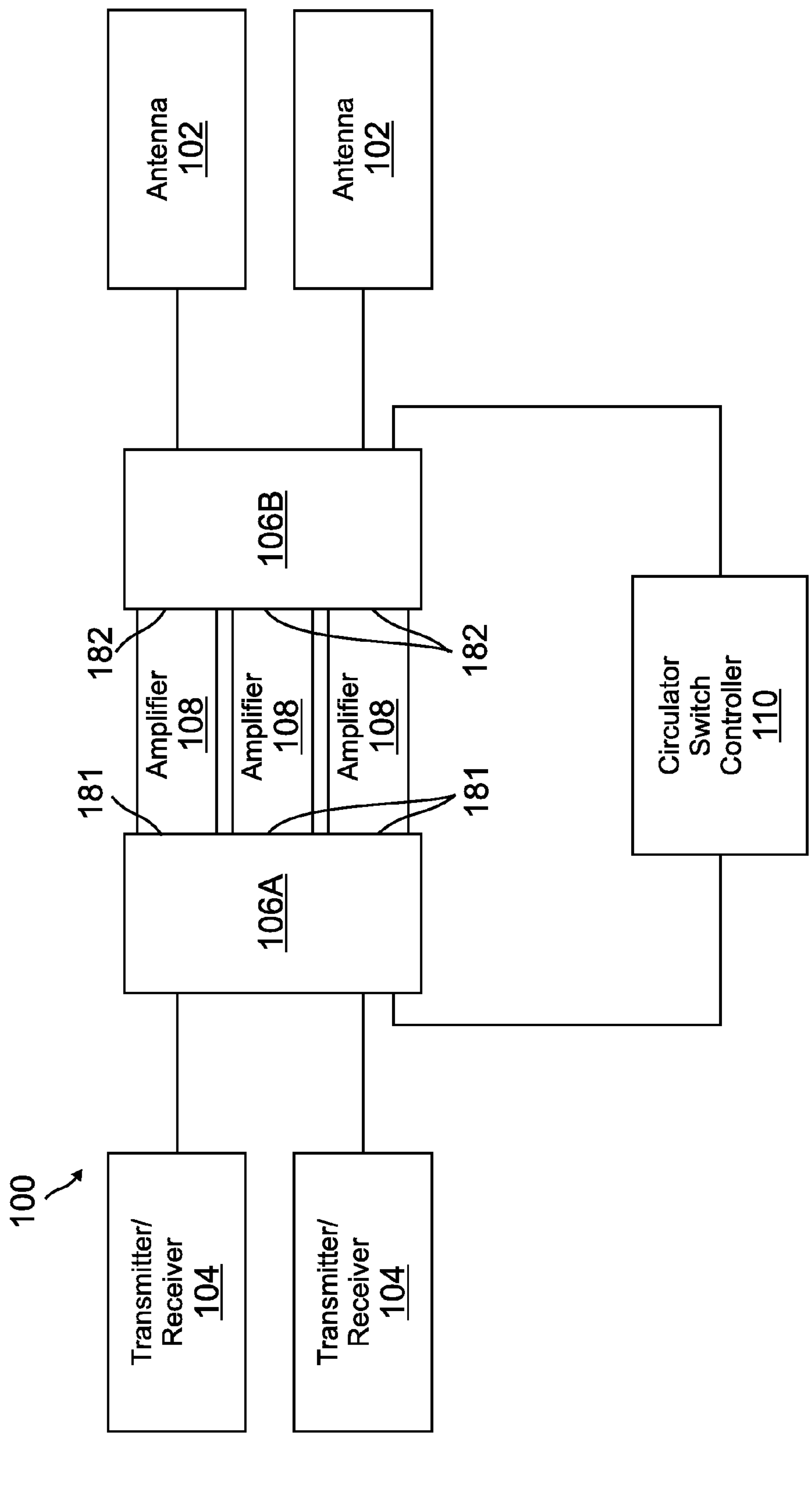
Antenna 102
Antenna 102
106B
182
182
Amplifier 108
Amplifier 108
Amplifier 108
181
181
106A
Circulator Switch Controller 110
100
Transmitter/ Receiver 104
Transmitter/ Receiver 104

FIG. 1

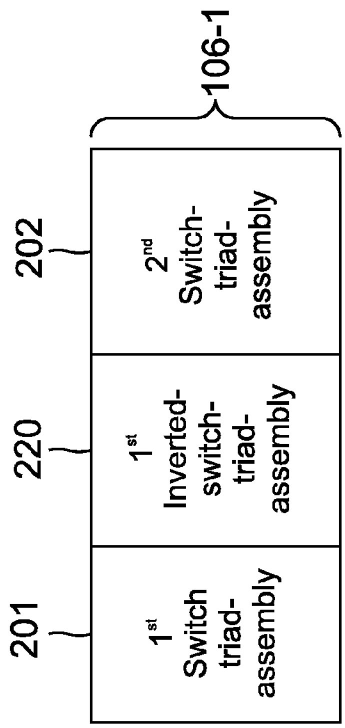
106-1
201
1st Switch triad-assembly
220
1st Inverted-switch-triad-assembly
202
2nd Switch-triad-assembly

FIG. 2A

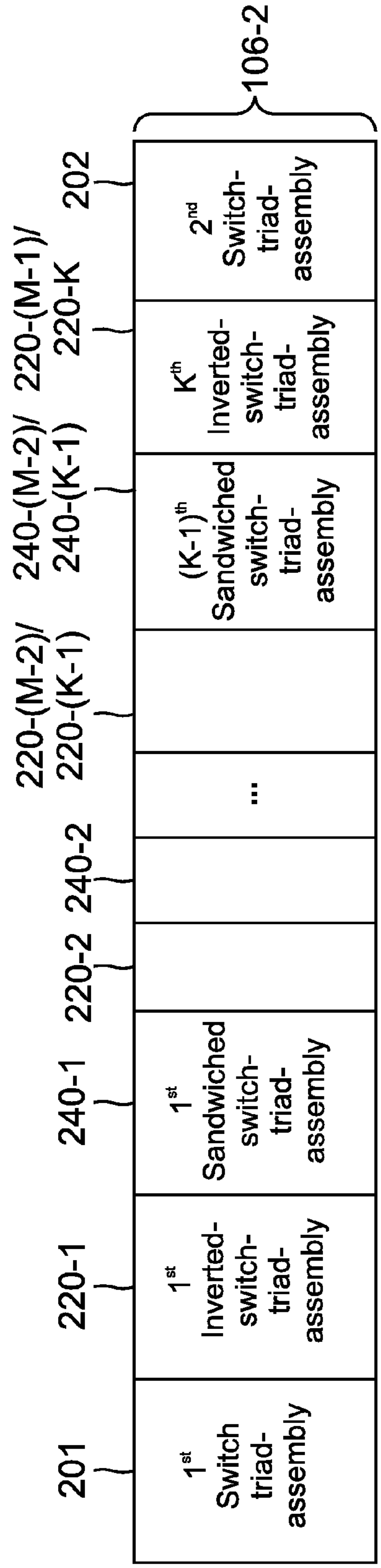
106-2
201
1st Switch triad-assembly
220-1
1st Inverted-switch-triad-assembly
240-1
1st Sandwiched switch-triad-assembly
220-2
240-2
...
220-(M-2)/
220-(K-1)
240-(M-2)/
240-(K-1)
(K-1)th Sandwiched switch-triad-assembly
220-(M-1)/
220-K
Kth Inverted-switch-triad-assembly
202
2nd Switch-triad-assembly

FIG. 2B

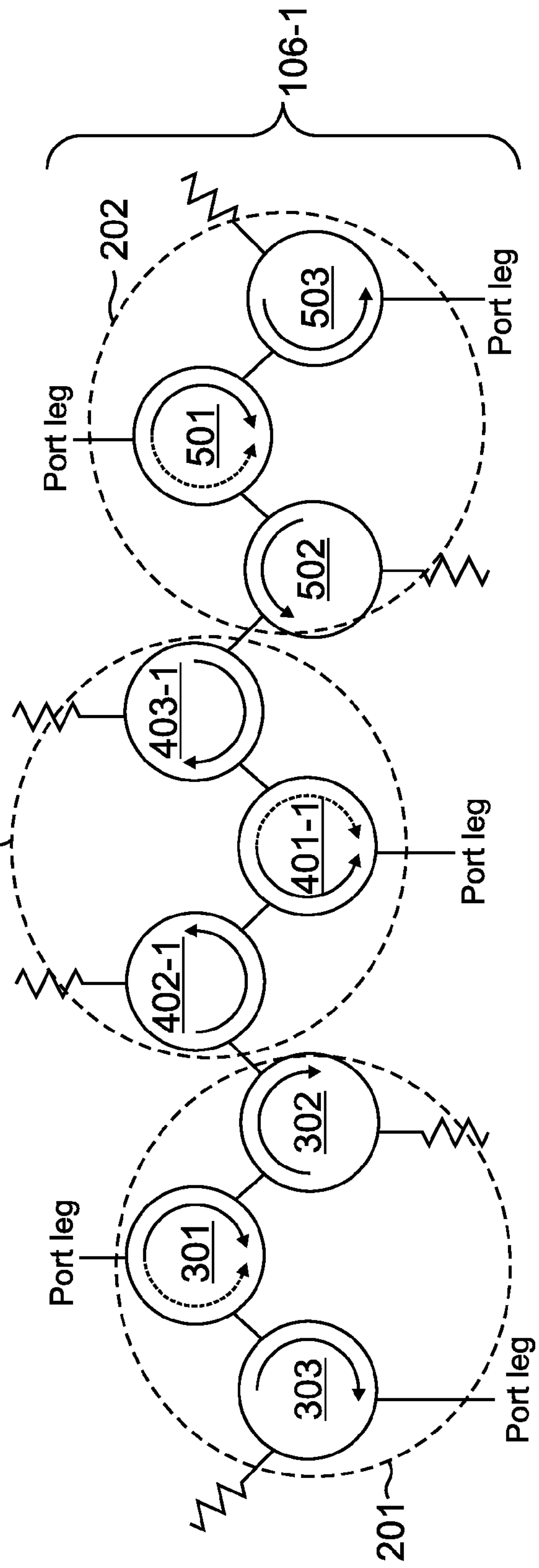
106-1
202
Port leg
503
Port leg
501
502
220-1
403-1
Port leg
401-1
402-1
302
Port leg
301
303
Port leg
201

FIG. 3

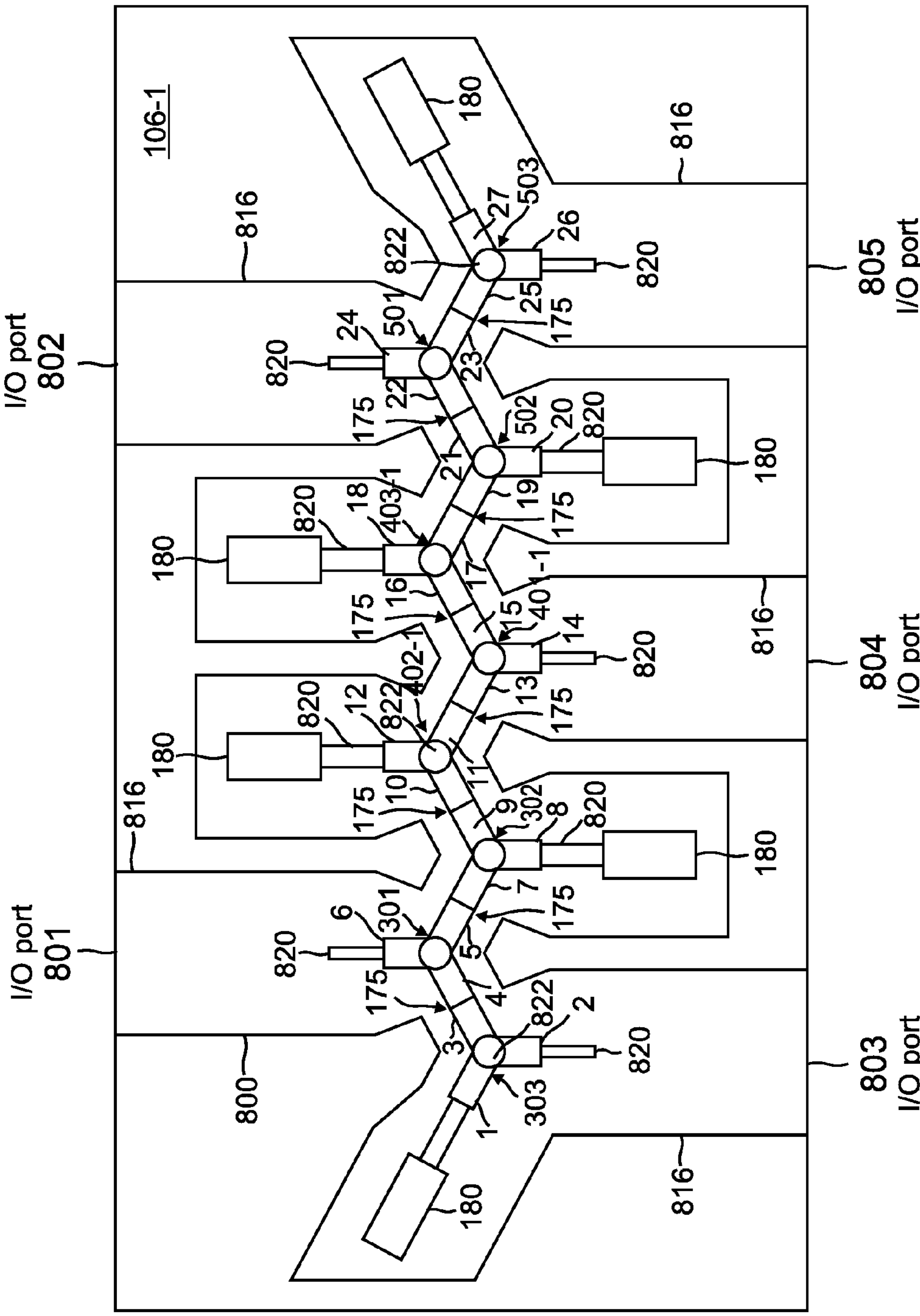
106-1
I/O port 801
I/O port 802
I/O port 803
I/O port 804
I/O port 805
800
816
820
822
175
180
301
302
303
401-1
402-1
403-1
501
502
503
1
2
3
4
5
6
7
8
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FIG. 4

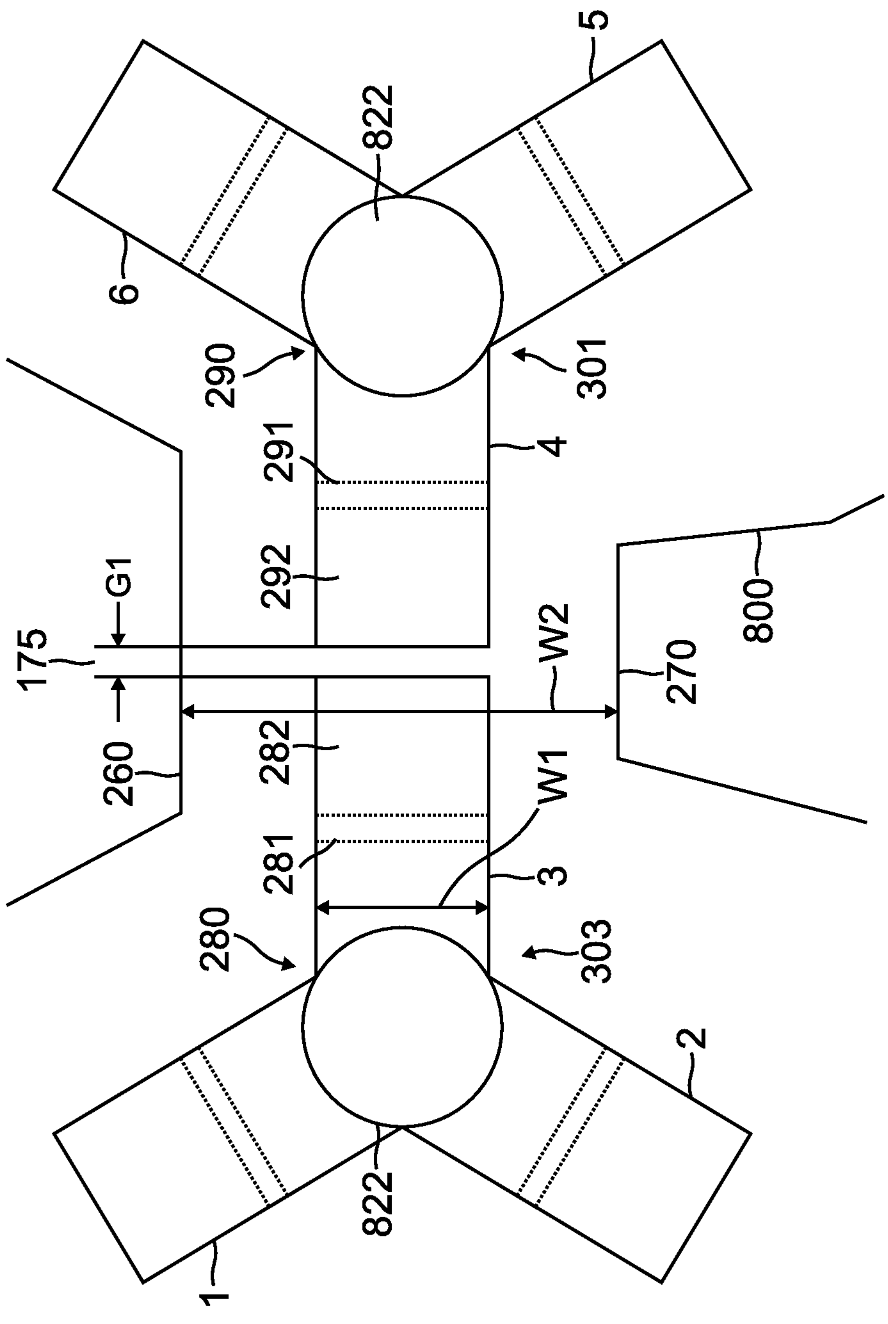

5
822
6
290
301
291
4
292
G1
175
W2
800
270
260
282
W1
281
3
280
303
2
822
1

FIG. 5

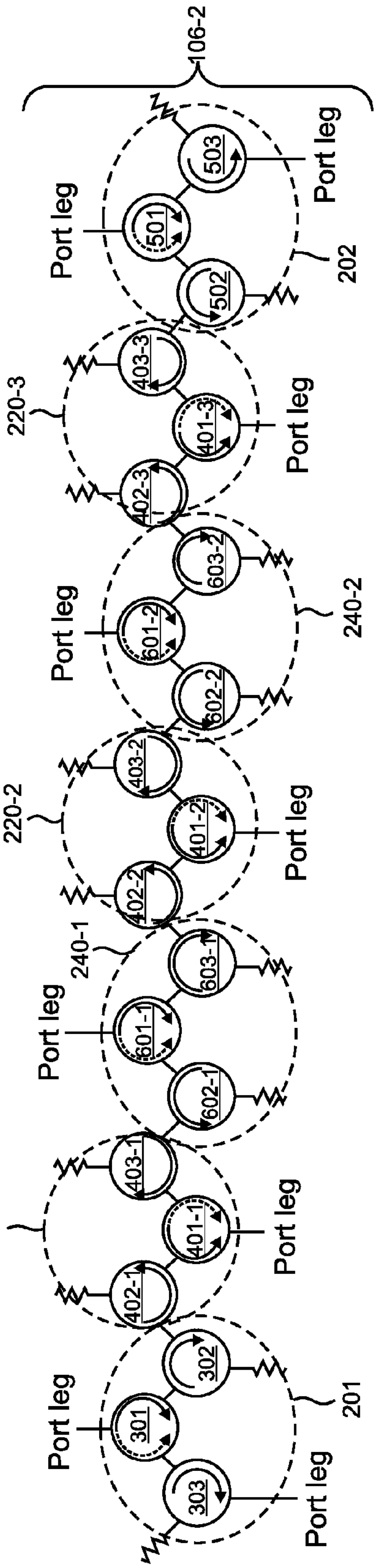

106-2
Port leg
503
Port leg
501
502
202
403-3
220-3
401-3
Port leg
402-3
603-2
Port leg
601-2
240-2
602-2
403-2
220-2
401-2
Port leg
402-2
240-1
603-1
Port leg
601-1
602-1
403-1
220-1
401-1
Port leg
402-1
302
Port leg
301
201
303
Port leg

FIG. 6

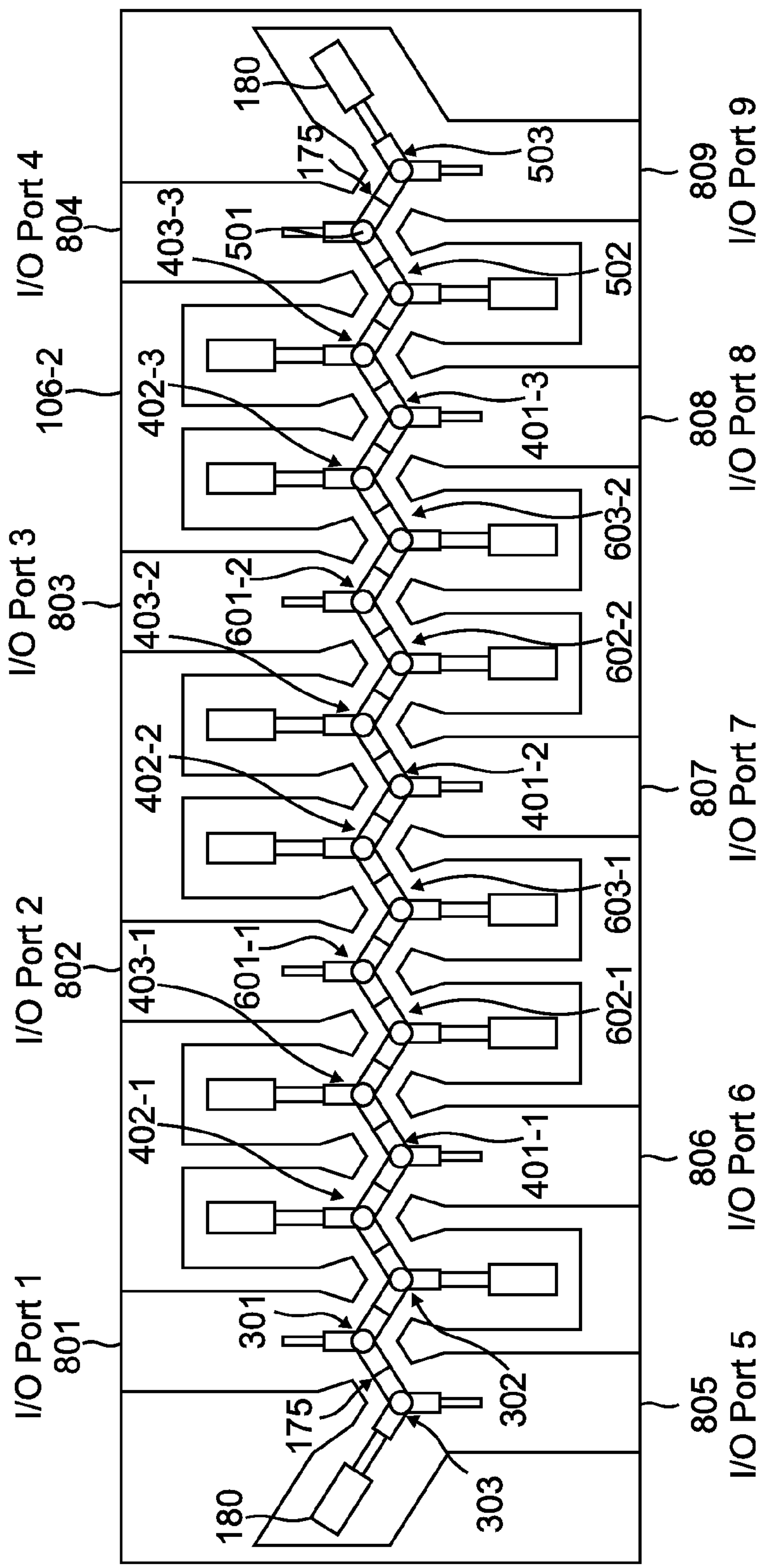

180
175
503
809
I/O Port 9
I/O Port 4
804
403-3
501
502
106-2
402-3
401-3
808
I/O Port 8
603-2
I/O Port 3
803
403-2
601-2
602-2
402-2
401-2
807
I/O Port 7
603-1
I/O Port 2
802
403-1
601-1
602-1
402-1
401-1
806
I/O Port 6
I/O Port 1
801
301
302
175
805
I/O Port 5
180
303

FIG. 7

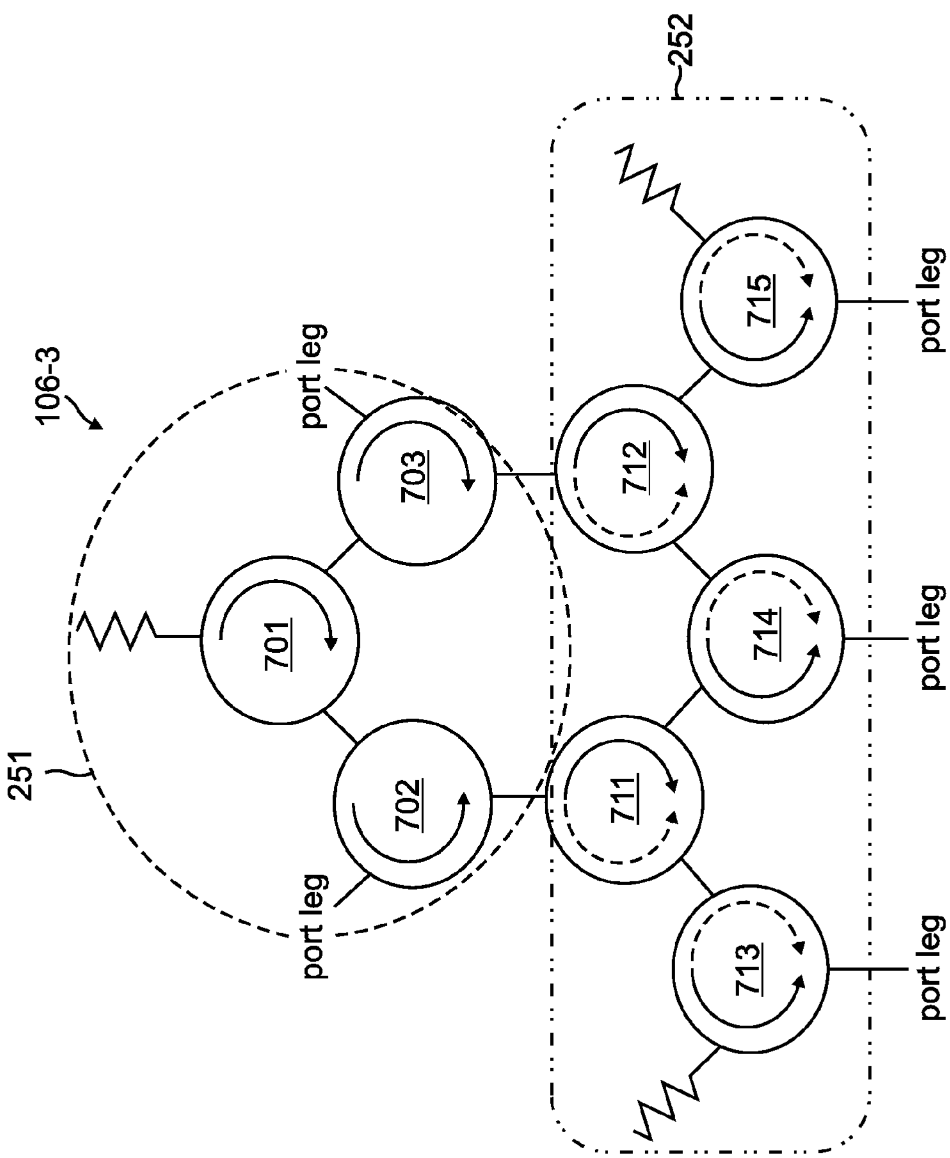
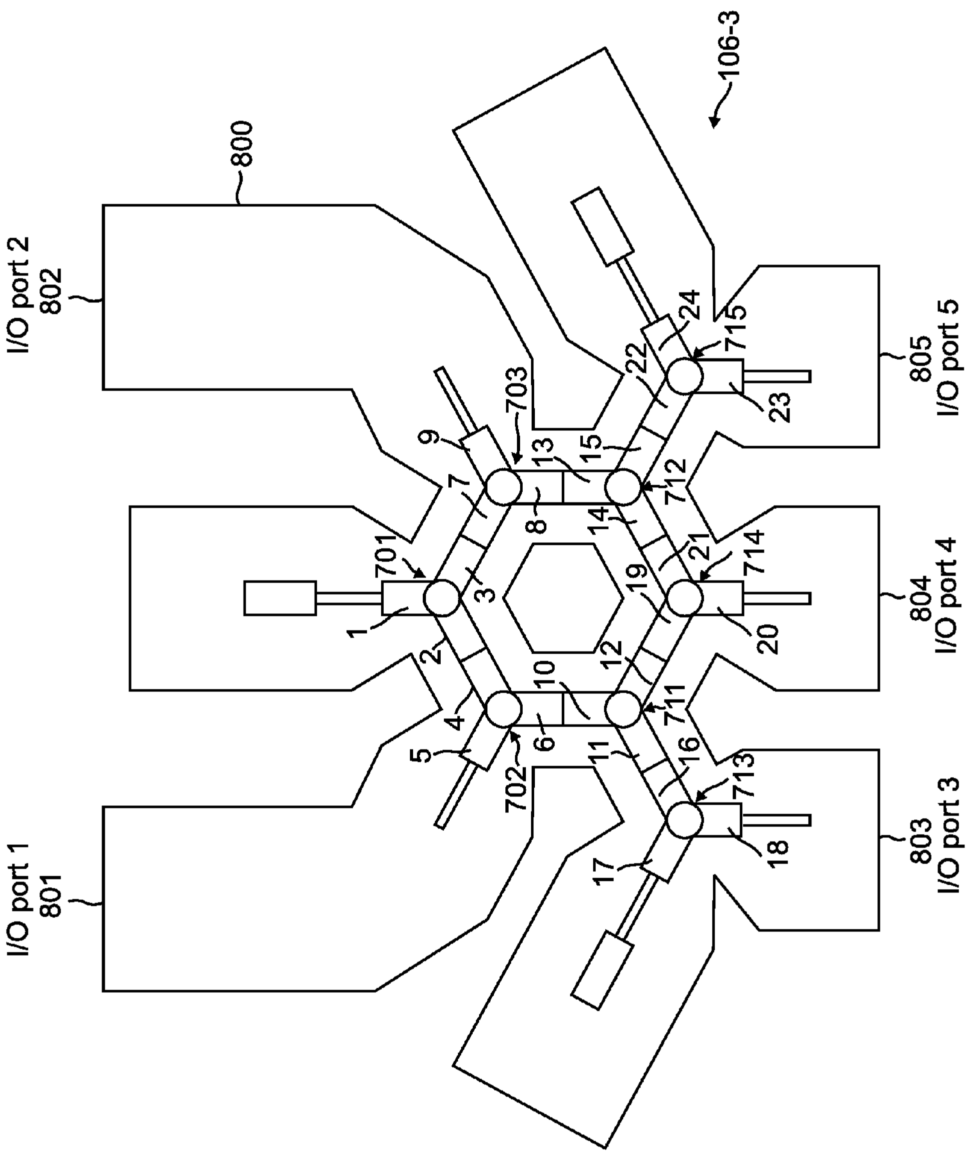

106-3
251
252
701
702
703
711
712
713
714
715
port leg
port leg
port leg
port leg
port leg
port leg

FIG. 8


106-3
800
I/O port 1
801
I/O port 2
802
803
I/O port 3
804
I/O port 4
805
I/O port 5
701
702
703
711
712
713
714
715
1
2
3
4
5
6
7
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9
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11
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23
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FIG. 9

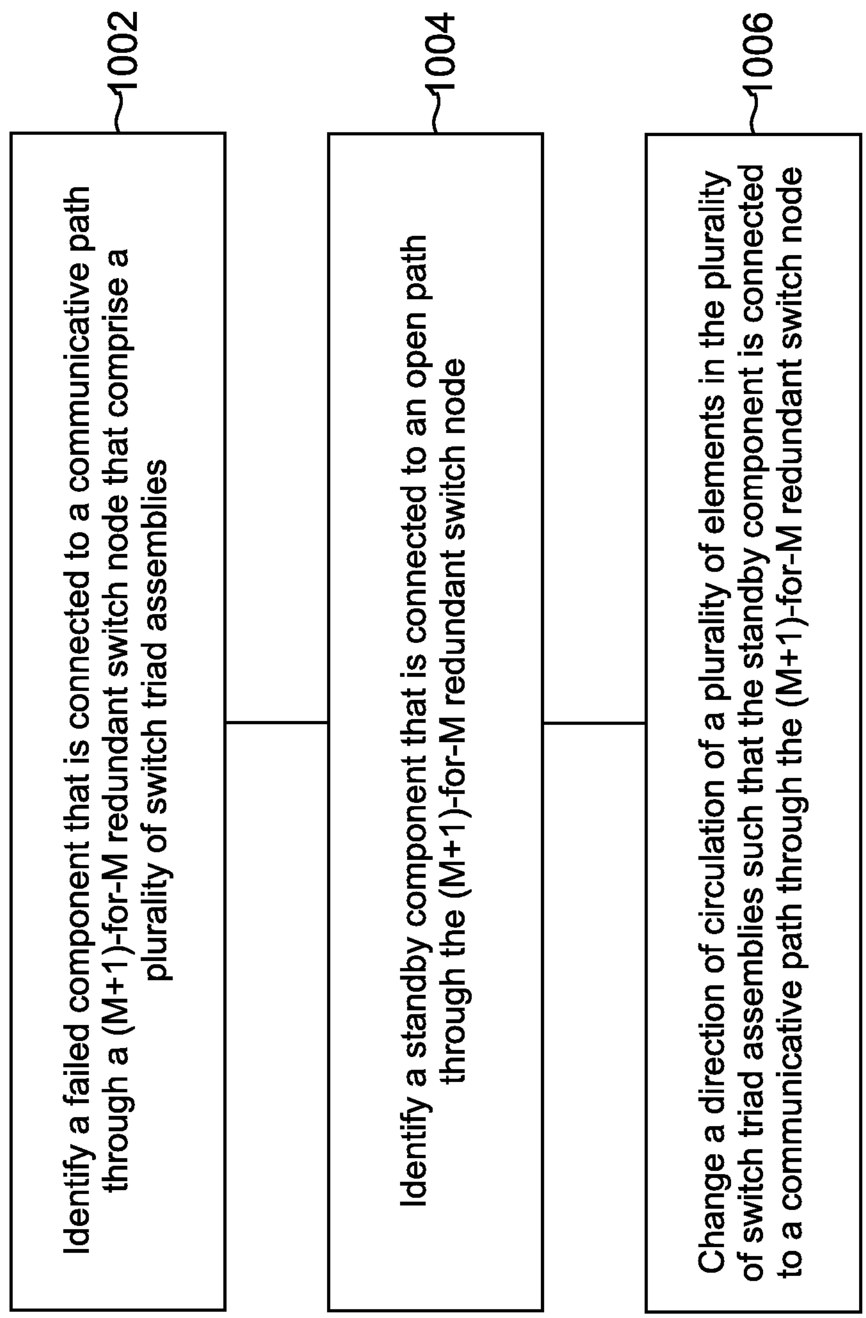
1002
Identify a failed component that is connected to a communicative path through a (M+1)-for-M redundant switch node that comprise a plurality of switch triad assemblies
1004
Identify a standby component that is connected to an open path through the (M+1)-for-M redundant switch node
1006
Change a direction of circulation of a plurality of elements in the plurality of switch triad assemblies such that the standby component is connected to a communicative path through the (M+1)-for-M redundant switch node

FIG. 10

(M+1)-FOR-M FERRITE REDUNDANCY SWITCH AND SWITCH SYSTEM

BACKGROUND

In some communication networks, certain communication nodes in the network are not easily accessible for repairs in the event that equipment on the communication node experiences a failure. For example, communication nodes located in space are practically inaccessible and, as such, that failed equipment cannot be repaired. To prevent the failures from affecting the operation of the communication node, the communication equipment on the communication node includes standby equipment that increases the redundancy of any communication paths through the communication equipment. To control which communication paths are used through the communication equipment, a switch system is used to switch a communication path from failed equipment to standby equipment.

Since low noise amplifiers are prone to failures, a communication node typically includes at least one spare amplifier depending on the size of the system. A switch system can be implemented using a network of switching ferrite circulators. Upon experiencing a failure of a low noise amplifier, the system switches a communication path from an input through the switch system without affecting other communication paths through the switch system.

For the reasons stated above and for other reasons stated below which will become apparent to those skilled in the art upon reading and understanding the specification, there is a need in the art for improved systems and methods for switch system is used to switch a communication path from failed equipment to standby equipment.

SUMMARY

The embodiments of the present invention provide methods and systems for a modular ferrite switch for constructing switch systems and will be understood by reading and studying the following specification.

The present application relates to an (M+1)-for-M redundant switch, where M is an integer greater than 1. The (M+1)-for-M redundant switch includes a first switch-triad-assembly, a second switch-triad-assembly, and at least one inverted-switch-triad-assembly. The first switch-triad-assembly includes a first switching element circulator and two element isolators. The second switch-triad-assembly includes a second switching element circulator and two element isolators. The at least one inverted-switch-triad-assembly includes a third switching element circulator and two element isolators. One of the element isolators of the first switch-triad-assembly is arranged to couple power with one of the two element isolators of one of the at least one inverted-switch-triad-assembly. One of the element isolators of the second switch-triad-assembly is arranged to couple power with another one of the two element isolators of one of the at least one inverted-switch-triad-assembly.

DRAWINGS

Understanding that the drawings depict only exemplary embodiments and are not therefore to be considered limiting in scope, the exemplary embodiments will be described with additional specificity and detail through the use of the accompanying drawings, in which:

FIG. **1** is a block diagram of an embodiment of an (M+1)-for-M redundant switch node that includes two (M+1)-for-M redundant switches in accordance with the present application;

FIGS. **2**A and **2**B are a block diagrams of embodiments of (M+1)-for-M redundant switches in the switch node of FIG. **1** in accordance with the present application;

FIG. **3** is a schematic illustration of an embodiment of an (M+1)-for-M redundant switch configuration in accordance with the present application;

FIG. **4** is a top view of a switch system including an (M+1)-for-M redundant switch configured as shown in FIG. **3** and positioned in a waveguide structure in accordance with the present application;

FIG. **5** shows a magnified view of a portion of the (M+1)-for-M redundant switch of FIG. **3** in the waveguide structure of FIG. **4**;

FIG. **6** is a schematic illustration of an embodiment of an (M+1)-for-M redundant switch configuration in accordance with the present application;

FIG. **7** is a top view of a switch system including an (M+1)-for-M redundant switch configured as shown in FIG. **6** and positioned in a waveguide structure in accordance with the present application;

FIG. **8** is a schematic illustration of an embodiment of a 3-for-2 redundant switch configuration in accordance with the present application;

FIG. **9** is a top view of a switch system including the 3-for-2 redundant switch configured as shown in FIG. **8** and positioned in a waveguide structure in accordance with the present application; and

FIG. **10** is a flow diagram of a method for routing signals through a circulator redundancy network in one embodiment described in the present disclosure.

In accordance with common practice, the various described features are not drawn to scale but are drawn to emphasize features relevant to the present invention. Reference characters denote like elements throughout figures and text.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of specific illustrative embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that logical, mechanical and electrical changes may be made without departing from the scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense.

The embodiments of switches described herein provide ferrite switch configurations for (M+1)-to-(M) that utilize reduced size switches. The terms “ferrite material” and “ferrimagnetic material” are used interchangeably herein. The ferrite elements (also referred to herein as “elements”) described herein are made from ferrite, garnet, or other ferrimagnetic materials. For small satellites, the tradeoff of high reliability versus small size, mass, and cost is tipped heavily to size/mass/cost reductions. Redundancy may not even be required in small satellites, but if required, it will be required at a low rate of spares, such as 3-for-2, 4-for-3, or 5-for-4. The embodiments of switches described herein provide (M+1)-for-M switching with improved performance and reduced size over the currently available (M+1)-for-M switch configurations.

The input/output ports and isolator loads of the currently available (M+1)-for-M switches are too close to one another to be implemented entirely with the reduced-size switches described herein, embodiments of which have a de minimus gap between adjacent legs of at least two ferrite elements that form the switch. Therefore, currently available (M+1)-for-M switches have a size, mass, and insertion loss that is greater than the size, mass and insertion loss of the of the (M+1)-for-M redundant switches described herein.

Various implementations of switching nodes, which provide redundancy to allow for a failure in a communication path through a switching node, are described herein. Further, the implementations described herein further provide switching nodes where the communication path of a channel can change without affecting the communication paths of other channels when the switching network experiences a failure, such as an amplifier failure. The switch nodes are bidirectional. The ports of the waveguides described herein are functional as both input ports and output ports depending on the direction of propagation of the electro-magnetic fields. Thus, the (M+1)-for-M redundant switches have (M+1) input ports and M output ports for one direction of propagation of the electro-magnetic fields, and have (M+1) output ports and M input ports for the opposite direction of propagation of the electro-magnetic fields. The ports of the waveguides are also referred to here as "input/output ports", "I/O ports", and "waveguide ports". The legs of the circulator elements, which are positioned in the waveguides that terminate with open-ended I/O ports, are referred to herein as "port legs" or "I/O port legs".

FIG. **1** is a block diagram of an embodiment of a switch node **100** that includes two (M+1)-for-M redundant switches **106** in accordance with the present application. The switch node **100** is useful for smaller satellites. The switch node **100** includes two (M+1)-for-M redundant switches **106** and a plurality of (M+1) components **108**. M is an integer greater than 1 and, for the exemplary case shown in FIG. **1**, M=2. Thus, for the exemplary case shown in FIG. **1**, the two (M+1)-for-M redundant switches **106** are 3-for-2 redundant switches **106** coupled to three components **108**. The two (M+1)-for-M redundant switches **106** include a first (M+1)-for-M redundant switch **106**A and a second (M+1)-for-M redundant switch **106**B. The first (M+1)-for-M redundant switch **106**A and the second (M+1)-for-M redundant switch **106**B are referred to herein as a pair of (M+1)-for-M redundant switches **106**A and **106**B. For each pair of (M+1)-for-M redundant switches **106**A and **106**B, there are a respective (M+1) components **108**.

The switch node **100** is also referred to herein as an "(M+1)-for-M redundant ferrite switch node **100**", an "(M+1)-for-M redundant switch node **100**", and an "(M+1)-for-M ferrite redundancy switch node **100**". The "(M+1)-for-M redundant switch **106**" is also referred to herein as an "(M+1)-for-M redundant ferrite switches **106**" and an "(M+1)-for-M ferrite redundancy switches **106**".

The components **108** have a first input/output port **181** and a second input/output port **182**. The first (M+1)-for-M redundant switch **106**A is coupled to the first input/output ports **181** of the components **108**. The second (M+1)-for-M redundant switch **106**B is coupled to the second input/output ports **182** of the components **108**.

As shown in FIG. **1**, the components **108** are amplifiers **108**, but other types of components can be used in the switch nodes **100**. The two (M+1)-for-M redundant switches **106** are able to route a path through the (M+1)-for-M redundant ferrite switch node **100** when one component **108** in the (M+1) components **108** has failed.

The exemplary switch node **100** shown in FIG. **1** is part of a communication network that transmits and receives signals. For example, the switch node **100** receives a signal through at least one antenna **102**. The signal is amplified by at least one amplifier **108** and is then processed by at least one transmitter/receiver **104**. Typically, each operational amplifier is communicatively coupled between a respective transmitter/receiver **104** and antenna **102**. In at least one implementation, the amplifier **108** may be a low noise amplifier (LNA), a power amplifier, a travelling wave tube amplifier (TWTA), or the like. Also, in certain implementations, the transmitter/receiver **104** provides a signal that is amplified by the amplifiers **108** and then provided to the antenna **102** for radiation to another communication node in the communication network. In certain embodiments, the switch node **100** is implemented on a platform that is inaccessible for repairs when a component on the system experiences a fault. For example, the switch node **100** may be implemented on a satellite located in space or other inaccessible location. In certain embodiments, the switch node **100** is implemented on a platform that is accessible, but is remote and difficult to access (for example, located in Antarctica) for repairs when a component on the system experiences a fault.

An amplifier **108** in the switch node **100** may experience a failure during the life of the switch node **100**. To prevent the failure from negatively affecting the operation of the switch node **100**, when the switch node **100** begins operation, the switch node **100** includes one standby amplifier **108** to be used in the event that an operating amplifier fails. When an operating amplifier fails, a circulator switch controller **110** changes a communication path that diverts away from the failed amplifier **108** to pass through the standby amplifier **108**. Specifically, the non-operational amplifier becomes operational upon being communicatively coupled to the transmitter/receiver **104** and antenna **102**, while the failed amplifier **108** becomes non-operational. In this manner, the switch node **100** remains operational when an amplifier **108** fails.

As shown in FIG. **1**, the amplifiers **108** are used as examples of electronic components, where the input/output ports **181**/**182** of the components **108** may connect to other components through transmission media that includes waveguides, microstrip, coaxial, and the like. In at least one implementation, the components **108** may connect to other components via adapters that allow the component to interface with other components fabricated in a different transmission media. It is intended that the switching node **100**, as described herein, can be used to change the RF path through an operating component to a standby component.

In at least one embodiment, an (M+1)-for-M redundant switch **106** contains multiple ferrite circulators that are connected to one another to provide switching capabilities between input/output legs. In certain implementations, the circulators in an (M+1)-for-M redundant switch **106** may be waveguide circulators, where each circulator has three legs arranged at 120° that meet in a common junction. The common junction may be loaded with a non-reciprocal material such as ferrite. In this latter embodiment, the (M+1)-for-M redundant switches **106** are (M+1)-for-M redundant ferrite switches **106**. The (M+1)-for-M redundant switches **106** that contain multiple ferrite circulators are able to be arranged with a reduced size as described below.

When a magnetizing field is created in the ferrite element that is located at the common junction, a gyromagnetic effect can be used to switch the microwave signal from one leg of the ferrite element to another leg of the ferrite element. By reversing the direction of the magnetizing field, the direction of switching between the legs of the ferrite element is reversed. Thus, a switching circulator is functionally equivalent to a fixed-bias circulator but has a selectable direction of circulation. Radio frequency (RF) energy (electromagnetic fields) can be routed with low insertion loss from one leg of the ferrite element in one waveguide arm of a waveguide structure to either of the two other legs of the ferrite element. If one of the legs of the ferrite element is terminated in a matched load, then the circulator acts as an isolator, with high loss in one direction of propagation and low loss in the other direction. Reversing the direction of the magnetizing field will reverse the direction of high and low isolation.

In certain embodiments, to control the direction of magnetization for the ferrite circulators in the (M+1)-for-M redundant switch **106**, the switch node **100** includes a circulator switch controller **110**. The circulator switch controller **110** sends electrical signals to the individual circulator elements that control the direction of circulation for each circulator. For example, the circulator switch controller **110** sends a high current pulse to a particular circulator that changes the direction of circulation in that circulator. In certain implementations, the circulator switch controller **110** includes a separate driver that is associated with each circulator in the switch node **100**, where the driver provides a switching signal to an individual circulator. In at least one other implementation, where switching time is not critical, the circulator switch controller **110** may include a single driver that is multiplexed to the separate circulators in the (M+1)-for-M redundant switch **106**. In a further embodiment, the circulator switch controller **110** includes an interface that allows a user to control the switching directly through another device.

The circulator switch controller **110** can include a processor to implement software to determine how to control the (M+1)-for-M redundant switch **106**. The methods for switching the (M+1)-for-M redundant switches described here may be implemented in analog electronic circuitry, digital electronic circuitry, or with a programmable processor, firmware, software, or in combinations of them. Apparatus embodying these techniques may include appropriate input and output devices, a programmable processor, and a storage medium tangibly embodying program instructions for execution by the programmable processor. Storage devices suitable for tangibly embodying program instructions and data include all forms of non-volatile memory, including by way of example semiconductor memory devices, such as EPROM, EEPROM, and flash memory devices; magnetic disks such as internal hard disks and removable disks; magneto-optical disks; and DVD disks. Any of the foregoing may be supplemented by, or incorporated in, specially-designed ASICs, or mixed-signal ASICs which contain analog and digital circuitry.

The (M+1)-for-M redundant switches **106** include multiple ferrite elements that typically have impedance-matching transitions between each ferrite element. For example, a conventional waveguide circulator may transition from one ferrite element to a dielectric-filled waveguide such as a quarter-wave dielectric transformer structure, to an air-filled waveguide, and then back to another dielectric-filled waveguide section and the next ferrite element. The conventional dielectric transformers are typically used to match the lower impedance of the ferrite element to that of an air-filled waveguide.

As stated above, an (M+1)-for-M redundant switch **106** may contain multiple waveguide circulators. Further, the (M+1)-for-M redundant switch **106** may also include multiple load elements for isolation of certain ports in some of the ferrite circulators. The circulators and load elements can be connected in various configurations according to the modular design of the (M+1)-for-M redundant switch **106** described herein. Isolators are added to the switch so that the impedance match for any one port is independent of the impedance match on the other ports and so that the RF energy input to one port does not interfere with the RF signals input to the other ports. If one of the legs of the waveguide circulators is terminated in a matched load, then the circulator acts as an isolator, with high loss in one direction of propagation and low loss in the other direction. Matched loads are used on any unneeded ports and unconnected interconnection ports. The element isolators are referred to herein as "non-switching ferrite element isolators" and "ferrite element isolators". In one implementation of this embodiment, the element isolator is a ferrite element isolator. In another implementation of this embodiment, the switching element circulator is a switching ferrite element circulator made from ferrite. The terms "switching element circulator", "switching ferrite element circulator", "ferrite circulators", "waveguide circulators" and "switching ferrite element" are used interchangeably herein.

In one implementation of this embodiment, there are two or more pairs of (M+1)-for-M redundant switches **106**A and **106**B and a respective more than two sets of (M+1) components **108**. For example, if the single (M+1)-for-M redundant switch **106**A at the input/output ports **181** of the components **108** is replaced by three (M+1)-for-M redundant switches **106**A at the input/output ports **181** of three sets of components **108**, then the single (M+1)-for-M redundant switch **106**B at the input/output ports **182** of the components **108** is replaced by three (M+1)-for-M redundant switches **106**B at the input/output port **182** of three sets of components **108**. In one implementation of this embodiment, a plurality of pairs of (M+1)-for-M redundant switches **106**A and **106**B are each functional with a respective plurality of antennas **102**. In an embodiment in which the node includes a plurality of pairs of (M+1)-for-M redundant switches **106**A/**106**B, there is a respective plurality of (M+1) components for each pair of (M+1)-for-M redundant switches **106**A/**106**B. The first input/output ports **181** of the (M+1) components **108** are coupled to a first one of the respective pair of (M+1)-for-M redundant switches **106**A/**106**B and second input/output ports **182** of the (M+1) components **108** are coupled to a second one of the respective pairs of (M+1)-for-M redundant switches **106**A/**106**B. Thus, there is no coupling between the (M+1)-for-M redundant switches **106**A on the first input/output port side. Likewise, there is no coupling between the (M+1)-for-M redundant switches **106**B on the second input/output port side.

FIGS. **2**A and **2**B are block diagrams of embodiments of (M+1)-for-M redundant switches **106** in the switch node **100** of FIG. **1** in accordance with the present application. The (M+1)-for-M redundant switches **106** includes a plurality of switch-triad-assemblies arranged in a simple, linear, alternating pattern. A switch-triad-assembly includes three elements that are configured in a manner so that one leg of each element is adjacent to one leg of a neighboring element. In one implementation of this embodiment, the elements are ferrite elements. Triad switches are described in greater detail in U.S. Pat. No. 6,885,257 titled "Multi-Junction Waveguide Circulator without Internal Transitions", which is herein incorporated by reference.

As shown in FIG. 2A, the (M+1)-for-M redundant switch **106-1** includes: a first switch-triad-assembly **201**; a second switch-triad-assembly **202**; and one inverted-switch-triad-assembly **220**. This is a 3-for-2 arrangement. Two 3-for-2 redundant switches **106-1** are coupled to three components **108** in a 3-for-2 redundant switch node **100** of FIG. **1**. An inverted-switch-triad-assembly includes a switching element circulator and two element isolators. Details about the 3-for-2 redundant switches **106-1** are described below with reference to FIGS. **3** and **4**.

As shown in FIG. 2B, the (M+1)-for-M redundant switch **106-2** includes: a first switch-triad-assembly **201**; a second switch-triad-assembly **202**; and a plurality of inverted-switch-triad-assemblies **220-1**, **220-2**, . . . , **220**-K, wherein K is an integer greater than one; and a plurality of sandwiched-switch-triad-assemblies **240-1**, **240-2**, . . . , **240**-(K−1). It is to be noted that in this case in which M≥3, K=M−1 and thus (K−1)=(M−2). Thus, **240**-(K−1) is also **240**-(M−2). A sandwiched switch-triad-assembly includes a switching element circulator and two element isolators, which are alternately interposed between inverted-switch-triad-assemblies **240** in an arrangement in which the element isolators of (K−1) sandwiched switch-triad-assemblies are arranged to couple power with the element isolators of K inverted-switch-triad-assemblies **220**.

In one implementation of this embodiment, the (M+1)-for-M redundant switch **106-2** is a 4-for-3 redundant switch **106-2**. In that case, the redundant switch **106-2** includes: the first switch-triad-assembly **201**; the second switch-triad-assembly **202**; two inverted-switch-triad-assemblies **220-1** and **220-2**, and one sandwiched-switch-triad-assembly **240-1**. Two 4-for-3 redundant switches **106-2** are coupled to four components **108** in a 4-for-3 redundant switch node **100** of FIG. **1**.

In another implementation of this embodiment, the (M+1)-for-M redundant switch **106-2** is a 5-for-4 redundant switch **106-2**. In that case, the redundant switch **106-2** includes: the first switch-triad-assembly **201**; the second switch-triad-assembly **202**; three inverted-switch-triad-assemblies **220-1**, **220-2**, **220-3**; and two sandwiched-switch-triad-assemblies **240-1** and **240-2**. Two 5-for-4 redundant switches **106-2** are coupled to five components **108** in a 5-for-4 redundant switch node **100** of FIG. **1**. Additional inverted-switch-triad-assemblies and sandwiched-switch-triad-assemblies can be added if more components **108** are required an (M+1)-for-M redundancy as is understandable to one skilled in the art upon reading and understanding this application.

The embodiment of a 3-for-2 redundant switch **106-1** and the configuration of elements in the first switch-triad-assembly **201**; the second switch-triad-assembly **202**; and the inverted-switch-triad-assembly **220** are described with reference to FIGS. **3** and **4**. An embodiment of a 5-for-4 redundant switch **106-2** and the configuration of elements in the first switch-triad-assembly **201**; the second switch-triad-assembly **202**; and the inverted-switch-triad-assemblies **220** (**1**-K); and the inverted-switch-triad-assemblies **240**(**1**-(K−1)) are described below in detail with reference to FIGS. **6** and **7**.

FIG. **3** is a schematic illustration of an embodiment of an (M+1)-for-M redundant switch configuration in accordance with the present application. In the configuration shown in FIG. **3**, M equals two. FIG. **4** is a top view of a switch system including an (M+1)-for-M redundant switch configured as shown in FIG. **3** and positioned in a waveguide structure **800** in accordance with the present application. In one implementation of this embodiment, the switch-triad-assemblies **201**, **202**, and **220-1** include ferrite elements. The following figures are described with reference to "ferrite elements".

As shown in FIG. **3**, the 3-for-2 redundant switch **106-1** includes a first switch-triad-assembly **201**, a second switch-triad-assembly **202**, and an inverted-switch-triad-assembly **220-1**. The first switch-triad-assembly **201** includes a first switching ferrite element circulator **301** and two ferrite element isolators **302** and **303**. The second switch-triad-assembly **202** includes a second switching ferrite element circulator **501** and two ferrite element isolators **502** and **503**. The inverted-switch-triad-assembly **220-1** includes a third switching ferrite element circulator **401-1** and two ferrite element isolators **402-1** and **403-1**. The ferrite element isolator **302** is arranged to couple power with the ferrite element isolator **402-1**. The ferrite element isolator **502** is arranged to couple power with the ferrite element isolator **403-1**.

In one implementation of this embodiment, the ferrite element isolators **302** and **303** are switching ferrite element circulators controlled to circulate electromagnetic fields in one direction. In another implementation of this embodiment, the ferrite element isolators **302**, **303**, **502**, and **503** are switching ferrite element circulators **302**, **303**, **502**, and **503**. As defined herein a switching ferrite element circulator is controlled to circulate electromagnetic fields in one direction until a failure requires at least one switching ferrite element circulator to circulate electromagnetic fields in an opposite direction. Thus, the switching ferrite element circulators **302**, **303**, **502**, and **503** are in a state and are only switched when a failure requires a switch after which the switching ferrite element circulators **302**, **303**, **502**, and **503** are held in that state until another failure requires a reconfiguration.

As shown in FIG. **4**, the (M+1)-for-M redundant switch **106-1** is positioned within a waveguide structure **800** that includes input/output (I/O) ports **801-805**. The ferrite elements are arranged to couple electromagnetic fields that propagate (typically as radio frequency waves) between adjacent legs of the elements **301-303**, **501-503**, **401-1**, **402-1**, and **403-1**. The waveguide structure **800**, which encloses the elements, guides the electromagnetic fields propagating through the elements. The waveguide structure **800** is formed from conductive material. The first switching ferrite element circulator **301** includes a port leg **6** in a first input/output port **801**. The ferrite element isolator **303** includes a port leg **2** in a third input/output port **803**. The second switching ferrite element circulator **501** includes a port leg **24** in a second input/output port **802**. The ferrite element isolator **503** includes a port leg **26** in a fifth input/output port **805**. The switching ferrite element circulator **401-1** includes a port leg **14** in a respective a fourth input/output port **804**. The leg **9** of ferrite element isolator **302** of the first switch-triad-assembly **201** is arranged to couple power with leg **10** of the ferrite element isolator **402-1** of the inverted-switch-triad-assembly **220-1** The leg **19** of the ferrite element isolator **502** of the second switch-triad-assembly **202** is arranged to couple power with leg **17** of the ferrite element isolator **403-1** of the inverted-switch-triad-assembly **220-1**.

In one implementation of this embodiment, the 3-for-2 redundant switch **106-1** shown in FIG. **4** is implemented in the node **100** of FIG. **1**. In this case, there are three components **108** for a respective pair of 3-for-2 redundant switches, wherein first input/output ports **181** of the three components are coupled to a first one of the two 3-for-2 redundant switches **106**A or **106**B (FIG. **1**) and second input/output ports **182** of the three components are coupled to a second one of the two 3-for-2 redundant switches **106**B or **106**A. In this case, first switch-triad-assembly **201**, the second switch-triad-assembly **202**, and the inverted-switch-triad-assembly **220-1** are able to route a path through the (M+1)-for-M redundant ferrite switch node **100** when a component **108** in the three components **108** has failed.

As shown in FIG. **4**, the legs of the ferrite elements that are not coupled to a leg of an adjacent ferrite element or an input/output port of the waveguide structure are loaded with an impedance matched load **180**.

In certain implementations, a quarter wave dielectric transformer **820** is attached to the ends of a ferrite element (e.g., ferrite element isolator **303**, first switching ferrite element circulator **301**, third switching ferrite element circulator **401-1**, second switching ferrite element circulator **501**, and ferrite element isolator **503**) that are farthest away from the middle of the respective ferrite elements. The quarter wave dielectric transformers **820** aid in the transition of the RF energy (electromagnetic fields) from a ferrite element to an air-filled waveguide arm represented generally at **816**. Dielectric transformers **820** are typically used to match the lower impedance of the ferrite elements **301**, **303**, **401-1**, **501**, and **503** to that of the air-filled waveguide arms **816**. In alternative implementations, ferrite elements (e.g., ferrite element isolator **303**, first switching ferrite element circulator **301**, third switching ferrite element circulator **401-1**, second switching ferrite element circulator **501**, and ferrite element isolator **503**) transition to the air-filled waveguide arm **816** without an aiding dielectric transformer **820**. To transition directly, without an aiding transformer, from the ferrite element to an air-filled waveguide arm **816**, the legs of the ferrite elements **301**, **303**, **401-1**, **501**, and **503** may be designed so that the impedance of the ferrite elements **301**, **303**, **401-1**, **501**, and **503** matches the impedance of the air-filled waveguide arm **816**. For example, the legs of the ferrite elements **301**, **303**, **401-1**, **501**, and **503** are designed to be narrower than corresponding switching elements that are designed to interface with dielectric transformers **820**. Further, the material that is used to fabricate the ferrite elements **301**, **303**, **401-1**, **501**, and **503** is selected to have a particular saturation magnetization value, such that the impedance of the ferrite elements **301**, **303**, **401-1**, **501**, and **503** matches the impedance of the air filled waveguide arm **816**.

In further embodiments, a top dielectric spacer **822** is disposed on the top surface of ferrite element that is parallel to the H-plane. Spacer **822** is used to position ferrite elements **301-303**, **401-1**, **402-1**, **403-1**, and **501-503** in the waveguide housing and to provide a thermal path out of ferrite elements **301-303**, **401-1**, **402-1**, **403-1**, and **501-503** for high power applications. Generally, two dielectric spacers **822** can be used. The two dielectric spacers **822** are located on opposite sides of the ferrite elements **301-303**, **401-1**, **402-1**, **403-1**, and **501-503**. All of the components described above are disposed within the waveguide structure **800**. The field guiding regions of the waveguide structure **800** (e.g., the waveguide arms **816**) are generally air-filled other than the ferrite element, transformers, spacers, winding, and the like. The waveguide input/output arms **816** provide interfaces for signal input and output. The waveguide input/output arms **816** end in opening that are referred to herein as waveguide input/output ports **801-805**.

No quarter-wave transformers are needed between the switch junctions. Gaps having de minimus length of unloaded waveguide are between the end faces of the elements that form the switch-triad-assemblies. In this manner, the 3-for-2 redundant switch **106-1** has a smaller assembly size than the conventional 3-for-2 redundant switches.

FIG. **5** shows a magnified view of a portion of the (M+1)-for-M redundant switch of FIG. **3** in the waveguide structure **800** of FIG. **4**. The interface between leg **3** of the ferrite element isolator **303** (element **303**) and leg **4** of the first switching ferrite element circulator **301**(element **301**) is shown in greater detail. The configuration of interface between the legs **3** and **4** is exemplary of the interfaces between the adjacent legs in the (M+1)-for-M redundant switch **106-1** as shown in FIG. **4**. For example, in one implementation of this embodiment, the interface between the legs **9** and **10** is the same as the interface between the legs **3** and **4** shown in FIG. **5**.

The element **303** is shown with a resonant section **280**, a quarter-wave section **282**, and dashed lines **281** representing an aperture bored through the element **303** for the magnetizing winding. Ferrite element **301** is shown with a resonant section **290**, a quarter-wave ferrite section **292**, and dashed lines **291** representing an aperture bored through the ferrite element **301** for the magnetizing winding. A dielectric spacer **822** overlays a portion of the resonant sections **280** and **290**. The implementation of magnetizing windings is described in greater detail in the U.S. Pat. No. 6,885,257 titled "Multi-Junction Waveguide Circulator without Internal Transitions", which is herein incorporated by reference. The impedance matching approach shown in FIG. **5** requires only the use of the two quarter-wave ferrite sections **282** and **292** and a de minimus length G**1** of unloaded waveguide between the faces of the ferrite elements **303** and **301**. The length G**1** is a very small fraction of a wavelength; no greater than a tenth of a waveguide wavelength and on the order of a few thousandths of an inch in the exemplary design for the 27 to 31 GHz frequency range. In contrast, for conventional designs having a frequency range of 27 to 31 GHz, the separation between the faces of the ferrite elements is on the order of 0.5 inches or approximately one hundred times the separation between the faces of length G**1** employed in this invention. The length G**1** is kept short enough so that the standing waves generated by the impedance mismatches at the ferrite-to-air interfaces effectively cancel each other out. The impedance mismatches at the interfaces between the ferrite resonators **280** and **290** and the ferrite quarter-wave transformer sections **282** and **292**, respectively, are separated by a total of a half-wavelength of ferrite-loaded waveguide, so the standing waves generated by these impedance mismatches cancel out as well. Thus, a more compact matching network has been implemented for the microwave signal transition from one ferrite element **303** to a second ferrite element **301**.

As stated above, the adjacent legs are located in close proximity to one another so that there is a de minimus air gap **175** of length G**1** between them. The "de minimus air gap" is also referred to herein as a "gap". In this embodiment, the gap **175** serves two purposes. The ferrite elements **303** and **301** are both bonded to the conductive waveguide structure **800** through spacers **822**. If the (M+1)-for-M redundant switch **106-1** is used in a high power application or in an application that sees a wide range of temperatures, differences in the coefficients of thermal expansion between the ferrite elements **303** and **301**, the dielectric spacers **822**, and the conductive waveguide structure **800** will stress the adhesive bond lines. Simply stated, the longer the ferrite elements, the higher the stress in the bond lines, and the greater the chances of breaking a bond line or damaging a ferrite element. This de minimus gap **175** between the ferrite elements minimizes the bond-line stress. A second advantage of this de minimus gap **175** is to magnetically isolate the ferrite elements **303** and **301**. In this manner, when ferrite element **303** is biased in the desired direction, there will be no crosstalk to affect the magnetic bias fields that are present in the adjacent ferrite element **301**, and vise-versa.

By eliminating the conventional quarter-wave dielectric ferrite-to-air transformers and air-filled waveguide section in the transition between two ferrite elements **303** and **301**, the resulting matching circuit is essentially a half-wavelength section of ferrite-loaded waveguide. Care must be taken to design this ferrite-loaded waveguide section so that higher order modes cannot propagate and degrade the performance. In FIG. **5**, the distance W**1** denotes the width of each leg of the ferrite elements **303** and **301**. FIG. **5** also shows walls **260** and **270** of the waveguide structure **800** that are adjacent to the ferrite elements. Thus, in FIG. **5**, a wall **260** and a wall **270** are disposed in close proximity to the ferrite elements **303** and **301**. FIG. **5** also shows a distance W2 that is the distance between opposing walls **260** and **270**. The distance W2 must be kept short enough so as to prevent higher order modes from propagating, but also long enough so that the resonant design is not perturbed and so that the half-wavelength section of ferrite-loaded waveguide is still effective in canceling out the standing waves generated by the impedance mismatches at the resonant section-to-quarter-wave ferrite section interfaces.

For the design shown in FIG. **5**, the optimal distance W**2** was determined empirically, using finite element analysis software. In this design, for the Ka-band of frequency operation, the preferred relationship between distances W**1** and W**2** is described as follows: W**2** is no greater than 4×W**1** and W**2** is no less than 2×W**1**. However, it is understood that this dimensional relationship can be varied within the scope of the design of this invention, as required for optimum signal transfer with reduced loss and signal reflection.

In another implementation of this embodiment, there are no gaps between adjacent legs. For example, the ferrite elements can be manufactured from a single piece of ferrite, which results in no gap between the ferrite elements. Ferrite circulators where the junction between two adjacent ferrite elements is a continuous junction having no gap between the adjacent ferrite element legs are described in greater detail in U.S. Pat. No. 7,176,767 titled "Multi-Junction Waveguide Circulator with Elements Having No Discontinuities", which is herein incorporated by reference.

In this exemplary case, a continuous junction having no gap is provided between the leg **9** of the element isolator **302** of the first switch-triad-assembly **201** and the leg **10** of the element isolator **402-1**. Likewise, a continuous junction having no gap is provided between the leg **19** of the element isolator **502** of the second switch-triad-assembly **202** and the leg **17** of the element isolator **403-1**. For at least one of: the first switch-triad-assembly **201**; the second switch-triad-assembly **202**; and the at least one inverted-switch-triad-assembly **220-1**, a continuous junction having no gap is provided between a leg of the two element isolators and a leg of the switching element circulator. In this case, the gaps **175** shown in FIG. **4** are removed from FIG. **4**.

As shown in FIG. **4**, the use of the reduced size switches with the gap results in size savings of ⅓ over standard switches, so 9 of these interfacing junctions (i.e., interfaces with gaps **175**) are the equivalent size of 3 standard switch junctions, which is half the size of a standard 6 switch junction approach of a typical prior art switch system with air interfaces. The added switch junctions also naturally space out the input/output ports to allow for reasonable-sized flanges for the customer interfaces and keep the input ports (e.g., I/O ports **801** and **802**) on opposite faces of the output ports (e.g., I/O ports **803-805**) of the (M+1)-for-M redundant switch **106-1**. This separation between input and output ports is generally desired by a user for ease of system design.

As described above with reference to FIG. **2**B, embodiments of the (M+1)-for-M redundant switches described herein include a first switch-triad-assembly **201**, a second switch-triad-assembly **202**, a plurality of K inverted-switch-triad-assemblies **220**(**1**-K), and plurality of (K−1) sandwiched switch-triad-assemblies **240**(**1**-(K−1)), which are alternately interposed between the K inverted-switch-triad-assemblies **220**(**1**-K) or **220-1**, **220-2**, and **220-3**. The (K−1) sandwiched switch-triad-assemblies **240**(**1**-(K−1)) include a switching ferrite element circulator **601**-*i* and two ferrite element isolators **602**-*i* and **603**-*i*, where i is a positive integer.

FIG. **6** is a schematic illustration of an embodiment of an (M+1)-for-M redundant switch configuration in accordance with the present application. In the configuration shown in FIG. **6**, M equals four. Thus, the 3-for-2 pattern of FIGS. **3** and **4** is extended linearly for a 5-for-4 redundant switch **106-2** shown in FIG. **6** by the addition of two sandwiched switch-triad-assemblies **240-1** and **240-2** and two more inverted-switch-triad-assemblies **220-2** and **220-3**. FIG. **7** is a top view of a switch system including an (M+1)-for-M redundant switch **106-2** configured as shown in FIG. **6** and positioned in a waveguide structure **800** in accordance with the present application.

The ferrite element isolators **602**-*i* and **603**-*i* of the (K−1) sandwiched switch-triad-assemblies **240-1** and **240-2** are arranged to couple power with the ferrite element isolators **403**-*f* and **402**-*g* of the K inverted-switch-triad-assemblies **220-1**, **220-2**, and **220-3**, where f and g are is positive integers. The 5-for-4 redundant switch **106-2** is designed for the use of elements **301-303**, **501-503**, **401**(**1-3**), **402**(**1-3**), **403**(**1-3**), **601**(**1-2**), **602**(**1-2**), and **603**(**1-2**) in which adjacent legs are located in close proximity to one another so that there is a de minimus air gap **175** (FIG. **5**) of length G**1** between the adjacent legs as described above with reference to FIGS. **4** and **5**. Specifically, a gap **175** is provided between a leg of the ferrite element isolator **302** of the first switch-triad-assembly **201** and a leg of the ferrite element isolator **402-1** of the inverted-switch-triad-assembly **220-1**. Likewise, a gap **175** is provided between a leg of the ferrite element isolator **602-1** of the sandwiched switch-triad-assembly **240-1** and the adjacent leg of the ferrite element isolator **403-1** of the inverted-switch-triad-assembly **220-1** and a gap **175** is provided between a leg of the ferrite element isolator **603-1** of the sandwiched switch-triad-assembly **240-1** and the adjacent leg of the ferrite element isolator **402-2** of the inverted-switch-triad-assembly **220-2**. Additionally, a gap **175** is provided between a leg of the ferrite element isolator **502** of the second switch-triad-assembly **202** and a leg of the two ferrite element isolator **403-3**. In this manner, the schematic implementation of the 5-for-4 redundant switch **106-2** has a smaller assembly size than the conventional 5-for-4 redundant switches.

FIG. **8** is a schematic illustration of an embodiment of a 3-for-2 redundant switch configuration in accordance with the present application. FIG. **9** is a top view of a switch system including a 3-for-2 redundant switch **106-3** configured as shown in FIG. **8** and positioned in a waveguide structure **800** in accordance with the present application. The 3-for-2 redundant switch **106-3** includes a triad-assembly **251** that is coupled to a switch-penta-assembly **252**.

The triad-assembly **251** includes a first non-switching ferrite element isolator **701**, a second non-switching ferrite element isolator **702**, and a third non-switching ferrite element isolator **703**. The first non-switching ferrite element isolator **701** has a loaded leg **1**. The second non-switching ferrite element isolator **702** has a first port leg **5** in the I/O port **801** of the waveguide structure **800**. The third non-switching ferrite element isolator **703** has a second port leg **9** in the I/O port **802** of the waveguide structure **800**.

The switch-penta-assembly **252** includes five switching ferrite elements: a first switching ferrite element **711**; a second switching ferrite element **712**; a third switching ferrite element **713**; a fourth switching ferrite element **714**; and a fifth switching ferrite element **715**. Within the switch-penta-assembly **252**, the first and second ferrite elements **711** and **712** are coupled to a respective one of the second and third non-switching ferrite element isolators **702** and **703**. The leg **10** of first switching ferrite element **711** in switch-penta-assembly **252** is coupled to the leg **6** of second non-switching ferrite element isolator **702** in the triad-assembly **251**. The leg **13** of second switching ferrite element **712** in switch-penta-assembly **252** is coupled to the leg **8** of the third non-switching ferrite element isolator **703** in the triad-assembly **251**.

The other three switching ferrite elements **713**-**715** of the five switching ferrite element circulators **711**-**715** have port legs **18**, **20**, and **23**, respectively.

In order to reduce the size of the 3-for-2 redundant switch **106-3**, a gap **175** is provided between adjacent legs of the first and second non-switching ferrite element isolators **701** and **702**; a gap **175** is provided between adjacent legs of the first and third non-switching ferrite element isolators **701** and **703**; a gap **175** is provided between adjacent legs of the first switching ferrite element **711** and the third switching ferrite element **713**; a gap **175** is provided between adjacent legs of the first switching ferrite element **711** and the fourth switching ferrite element **714**; a gap **175** is provided between adjacent legs of the second switching ferrite element **712** and the fourth switching ferrite element **713**; a gap **175** is provided between adjacent legs of the second switching ferrite element **712** and the fifth switching ferrite element **715**; a de minimus gap is provided between adjacent legs of the second non-switching element isolator **702** and the first switching element circulator **711**; and a de minimus gap is provided between adjacent legs of the third non-switching element isolator **703** and the second switching element circulator **712**.

The function and structure of the ferrite elements in the triad-assembly **251** and the switch-penta-assembly **252** are similar to the function and structure of the elements described above with reference to FIGS. **3**, **4**, and **5** as is understandable to one skilled in the art upon reading and understanding this application.

FIG. **10** is a flow diagram of a method **1000** for switching communication paths through an (M+1)-for-M redundant switch node **100** (FIG. **1**) in a communication network. Method **1000** proceeds at **1002**, where a failed component **108** (FIG. **1**) is identified, where the failed component **108** is connected to a communicative path through an (M+1)-for-M redundant switch **106**-*i* (i=A and B in FIG. **1** and i=1, 2, and 3 in FIGS. **3**, **6**, and **8**, respectively) that includes a plurality of switch-triad-assemblies **201**, **202**, **220**, and/or **240**. For example, an (M+1)-for-M redundant switch node **100** may have multiple LNAs **108**, where some of the LNAs are standby LNAs in the event an operation LNA fails. Further, the operational LNA may connect to other components **108** on the switch node **100**. During the operation of the (M+1)-for-M redundant switch node **100**, the (M+1)-for-M redundant switch node **100** may monitor the operational LNAs **108** to determine when a failure occurs.

In certain implementation, when a failed component **108** is identified, method **1000** proceeds at **1004**, where a standby component **108** is identified, where the standby component is connected to an open path through the (M+1)-for-M redundant switches **106**A and **106**B in the (M+1)-for-M redundant switch node **100**. Method **1000** then proceeds at **1006** where a direction of circulation of a plurality of elements in the plurality of switch-triad-assemblies is changed such that the standby component **108** is connected to a communicative path through the (M+1)-for-M redundant switches **106**A and **106**B.

EXAMPLE EMBODIMENTS

Example 1 includes an (M+1)-for-M redundant switch, where M is an integer greater than 1, the (M+1)-for-M redundant switch comprising: a first switch-triad-assembly including a first switching element circulator and two element isolators; a second switch-triad-assembly including a second switching element circulator and two element isolators and; and at least one inverted-switch-triad-assembly including a third switching element circulator and two element isolators, wherein one of the element isolators of the first switch-triad-assembly is arranged to couple power with one of the two element isolators of one of the at least one inverted-switch-triad-assembly, and wherein one of the element isolators of the second switch-triad-assembly is arranged to couple power with another one of the two element isolators of one of the at least one inverted-switch-triad-assembly.

Example 2 includes the (M+1)-for-M redundant switch, of Example 1, wherein the at least one inverted-switch-triad-assembly is a positive integral number K of inverted-switch-triad-assemblies, where K is two or more, the (M+1)-for-M redundant switch further comprising: (K−1) sandwiched switch-triad-assemblies including a fourth switching element circulator and two element isolators, the plurality of (K−1) sandwiched switch-triad-assemblies alternately interposed between the K inverted-switch-triad-assemblies, wherein the element isolators of the (K−1) sandwiched switch-triad-assemblies are arranged to couple power with the element isolators of the K inverted-switch-triad-assemblies.

Example 3 includes the (M+1)-for-M redundant switch of Example 2, wherein de minimus gaps are provided between legs of the element isolators of the (K−1) sandwiched switch-triad-assemblies adjacent to the respective legs of the element isolators and of the K inverted-switch-triad-assemblies.

Example 4 includes the (M+1)-for-M redundant switch of any of Examples 1-3, wherein a de minimus gap is provided between a leg of one of the two element isolators of the first switch-triad-assembly and a leg of one of the two element isolators of one of the K inverted-switch-triad-assemblies.

Example 5 includes the (M+1)-for-M redundant switch of any of Examples 1-4, wherein a de minimus gap is provided between a leg of one of the two element isolators of the second switch-triad-assembly and a leg of one of the two element isolators of one of the K inverted-switch-triad-assemblies.

Example 6 includes the (M+1)-for-M redundant switch of any of Examples 1-5, wherein for at least one of: the first switch-triad-assembly; the second switch-triad-assembly; and the at least one inverted-switch-triad-assembly, a de minimus gap is provided between a leg of the two element isolators and a leg of the switching element circulator.

Example 7 includes the (M+1)-for-M redundant switch of any of Examples 1-6, wherein at least one leg of at least one of the two element isolators of the first switch-triad-assembly, the second switch-triad-assembly, and the at least one inverted-switch-triad-assembly is at least one loaded leg, and wherein at least one leg of the switching element circulator of the first switch-triad-assembly, the second switch-triad-assembly, and the at least one inverted-switch-triad-assembly is a port leg.

Example 8 includes the (M+1)-for-M redundant switch of any of Examples 1-7, wherein a continuous junction having no gap is provided between a leg of one of the two element isolators of the first switch-triad-assembly and a leg of one of the two element isolators of the K inverted-switch-triad-assemblies, and wherein a continuous junction having no gap is provided between a leg of one of the two element isolators of the second switch-triad-assembly and a leg of one of the two element isolators.

Example 9 includes the (M+1)-for-M redundant switch of any of Examples 1-8, wherein the element isolators are switching element circulators controlled to circulate electromagnetic fields in one direction.

Example 10 includes the (M+1)-for-M redundant switch of any of Examples 1-9, wherein the element isolators are switching element circulators controlled to circulate electromagnetic fields in one direction until a failure requires at least one switching element circulator to circulate electromagnetic fields in an opposite direction.

Example 11 includes an (M+1)-for-M redundant switch node, where M is an integer greater than 1, the system comprising: at least two (M+1)-for-M redundant switches, the at least two (M+1)-for-M redundant switches including: a first switch-triad-assembly including a first switching element circulator and two element isolators, wherein the first switching element circulator includes a port leg in a first input/output port, and wherein one of the two element isolators includes a port leg in a third input/output port; a second switch-triad-assembly including a second switching element circulator and two element isolators, wherein the second switching element circulator includes a second port leg in a second input/output port, and wherein one of the two element isolators includes a port leg in a fifth input/output port; and at least one inverted-switch-triad-assembly including a third switching element circulator and two element isolators, wherein the at least one third switching element circulator includes a respective port leg in a respective at least one third input/output port, wherein one of the element isolators of the first switch-triad-assembly is coupled to one of the two element isolators of one of the at least one inverted-switch-triad-assembly, and wherein the one of the element isolators of the second switch-triad-assembly is arranged to couple power with another one of the two element isolators of one of the at least one inverted-switch-triad-assembly; and (M+1) components for a respective pair of (M+1)-for-M redundant switches, wherein first input/output ports of the (M+1) components are coupled to a first one of the respective pair of (M+1)-for-M redundant switches and second input/output ports of the (M+1) components are coupled to a second one of the respective pair of (M+1)-for-M redundant switches, wherein the first switch-triad-assembly, the second switch-triad-assembly, and the at least one inverted-switch-triad-assembly are able to route a path through the (M+1)-for-M redundant switch node when a component in the (M+1) components associated with a respective pair of (M+1)-for-M redundant switches has failed.

Example 12 includes the (M+1)-for-M redundant switch node, of Example 11, further comprising: a waveguide structure in which the first switch-triad-assembly, the second switch-triad-assembly and the at least one inverted-switch-triad-assembly are positioned.

Example 13 includes the (M+1)-for-M redundant switch node, of any of Examples 11-12, wherein the at least one inverted-switch-triad-assembly is a positive integral number K of inverted-switch-triad-assemblies, where K is two or more, the (M+1)-for-M redundant switch further comprising: a plurality of (K−1) sandwiched switch-triad-assemblies, wherein a (K−1) sandwiched switch-triad-assembly includes a fourth switching element circulator and two element isolators, and wherein the plurality of (K−1) sandwiched switch-triad-assemblies are alternately interposed between the K inverted-switch-triad-assemblies, wherein the element isolators of the plurality of (K−1) sandwiched switch-triad-assemblies are arranged to couple power with the element isolators of the K inverted-switch-triad-assemblies, wherein the plurality of fourth switching element circulators in the respective plurality of (K−1) sandwiched switch-triad-assemblies include a respective plurality of port legs in a respective plurality of additional input/output ports, and wherein two element isolators in the respective plurality of (K−1) sandwiched switch-triad-assemblies are loaded.

Example 14 includes the (M+1)-for-M redundant switch node of Example 13, wherein de minimus gaps are provided between legs of the element isolators of the (K−1) sandwiched switch-triad-assemblies adjacent to the respective legs of the element isolators of the K inverted-switch-triad-assemblies.

Example 15 includes the (M+1)-for-M redundant switch node of any of Examples 11-14, wherein a de minimus gap is provided between a leg of one of the two element isolators of the first switch-triad-assembly and a leg of one of the two element isolators of one of the K inverted-switch-triad-assemblies, wherein a de minimus gap is provided between a leg of one of the two element isolators of the second switch-triad-assembly and a leg of one of the two element isolators of one of the K inverted-switch-triad-assemblies, and wherein for at least one of: the first switch-triad-assembly; the second switch-triad-assembly; and the at least one inverted-switch-triad-assembly, a de minimus gap is provided between a leg of the two element isolators and a leg of the switching element circulator.

Example 16 includes the (M+1)-for-M redundant switch node of any of Examples 11-15, wherein at least one leg of at least one of the two element isolators of the first switch-triad-assembly, the second switch-triad-assembly, and the at least one inverted-switch-triad-assembly is at least one loaded leg.

Example 17 includes the (M+1)-for-M redundant switch node of any of Examples 11-16, wherein a continuous junction having no gap is provided between a leg of one of the two element isolators of the first switch-triad-assembly and a leg of one of the two element isolators; wherein a continuous junction having no gap is provided between a leg of one of the two element isolators of the second switch-triad-assembly and a leg of one of the two element isolators; and wherein for at least one of: the first switch-triad-assembly; the second switch-triad-assembly; and the at least one inverted-switch-triad-assembly, a continuous junction having no gap is provided between a leg of the two element isolators and a leg of the switching element circulator.

Example 18 includes the (M+1)-for-M redundant switch node of any of Examples 11-17, wherein the element isolators are switching element circulators controlled to circulate electromagnetic fields in one direction until a failure requires at least one switching element circulator to circulate electromagnetic fields in an opposite direction.

Example 19 includes a 3-for-2 redundant switch, comprising: a triad-assembly including a first non-switching element isolator, a second non-switching element isolator, and a third non-switching element isolator, wherein the first non-switching element isolator has a loaded leg, the second non-switching element isolator has a first port leg, and the third non-switching element isolator has a second port leg; and a switch-penta-assembly including a first switching element circulator, a second switching element circulator, a third switching element circulator, a fourth switching element circulator, and a fifth switching element circulator; and wherein the first and second switching element circulators are coupled to a respective one of the second and third non-switching element isolators, and the other three of the five switching element circulators have port legs.

Example 20 includes the 3-for-2 redundant switch of Example 19, wherein a de minimus gap is provided between adjacent legs of the first and second non-switching element isolators, wherein a de minimus gap is provided between adjacent legs of the first and third non-switching element isolators, wherein a de minimus gap is provided between adjacent legs of the first switching element circulator and the third switching element circulator, wherein a de minimus gap is provided between adjacent legs of the first switching element circulator and the fourth switching element circulator, wherein a de minimus gap is provided between adjacent legs of the second switching element circulator and the fourth switching element circulator, wherein a de minimus gap is provided between adjacent legs of the second switching element circulator and the fifth switching element circulator, wherein a de minimus gap is provided between adjacent legs of the second switching element circulator and the fifth switching element circulator, wherein a de minimus gap is provided between adjacent legs of the second non-switching element isolator and the first switching element circulator, and wherein a de minimus gap is provided between adjacent legs of the third non-switching element isolator and the second switching element circulator.

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement, which is calculated to achieve the same purpose, may be substituted for the specific embodiment shown. This application is intended to cover any adaptations or variations of the present invention. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

What is claimed is:

1. An (M+1)-for-M redundant switch, where M is an integer greater than 1, the (M+1)-for-M redundant switch comprising:

a first switch-triad-assembly including a first switching element circulator and two element isolators;

a second switch-triad-assembly including a second switching element circulator and two element isolators; and

at least one inverted-switch-triad-assembly including a third switching element circulator and two element isolators,

wherein one of the element isolators of the first switch-triad-assembly is arranged to couple power with one of the two element isolators of one of the at least one inverted-switch-triad-assembly, and

wherein one of the element isolators of the second switch-triad-assembly is arranged to couple power with another one of the two element isolators of one of the at least one inverted-switch-triad-assembly.

2. The (M+1)-for-M redundant switch, of claim **1**, wherein the at least one inverted-switch-triad-assembly is a positive integral number K of inverted-switch-triad-assemblies, where K is two or more, the (M+1)-for-M redundant switch further comprising:

(K−1) sandwiched switch-triad-assemblies including a fourth switching element circulator and two element isolators, the plurality of (K−1) sandwiched switch-triad-assemblies alternately interposed between the K inverted-switch-triad-assemblies,

wherein the element isolators of the (K−1) sandwiched switch-triad-assemblies are arranged to couple power with the element isolators of the K inverted-switch-triad-assemblies.

3. The (M+1)-for-M redundant switch of claim **2**,

wherein de minimus gaps are provided between legs of the element isolators of the (K−1) sandwiched switch-triad-assemblies adjacent to the respective legs of the element isolators and of the K inverted-switch-triad-assemblies.

4. The (M+1)-for-M redundant switch of claim **1**,

wherein a de minimus gap is provided between a leg of one of the two element isolators of the first switch-triad-assembly and a leg of one of the two element isolators of one of the K inverted-switch-triad-assemblies.

5. The (M+1)-for-M redundant switch of claim **1**,

wherein a de minimus gap is provided between a leg of one of the two element isolators of the second switch-triad-assembly and a leg of one of the two element isolators of one of the K inverted-switch-triad-assemblies.

6. The (M+1)-for-M redundant switch of claim **1**, wherein for at least one of: the first switch-triad-assembly; the second switch-triad-assembly; and the at least one inverted-switch-triad-assembly, a de minimus gap is provided between a leg of the two element isolators and a leg of the switching element circulator.

7. The (M+1)-for-M redundant switch of claim **1**, wherein at least one leg of at least one of the two element isolators of the first switch-triad-assembly, the second switch-triad-assembly, and the at least one inverted-switch-triad-assembly is at least one loaded leg, and

wherein at least one leg of the switching element circulator of the first switch-triad-assembly, the second switch-triad-assembly, and the at least one inverted-switch-triad-assembly is a port leg.

8. The (M+1)-for-M redundant switch of claim **1**, wherein a continuous junction having no gap is provided between a leg of one of the two element isolators of the first switch-triad-assembly and a leg of one of the two element isolators of the K inverted-switch-triad-assemblies, and wherein a continuous junction having no gap is provided between a leg of one of the two element isolators of the second switch-triad-assembly and a leg of one of the two element isolators.

9. The (M+1)-for-M redundant switch of claim **1**, wherein the element isolators are switching element circulators controlled to circulate electromagnetic fields in one direction.

10. The (M+1)-for-M redundant switch of claim **1**, wherein the element isolators are switching element circulators controlled to circulate electromagnetic fields in one direction until a failure requires at least one switching element circulator to circulate electromagnetic fields in an opposite direction.

11. An (M+1)-for-M redundant switch node, where M is an integer greater than 1, the system comprising:

at least two (M+1)-for-M redundant switches, the at least two (M+1)-for-M redundant switches including:

a first switch-triad-assembly including a first switching element circulator and two element isolators, wherein the first switching element circulator includes a port leg in a first input/output port, and wherein one of the two element isolators includes a port leg in a third input/output port;

a second switch-triad-assembly including a second switching element circulator and two element isolators, wherein the second switching element circulator includes a second port leg in a second input/output port, and wherein one of the two element isolators includes a port leg in a fifth input/output port; and

at least one inverted-switch-triad-assembly including a third switching element circulator and two element isolators, wherein the at least one third switching element circulator includes a respective port leg in a respective at least one third input/output port,

wherein one of the element isolators of the first switch-triad-assembly is coupled to one of the two element isolators of one of the at least one inverted-switch-triad-assembly, and

wherein the one of the element isolators of the second switch-triad-assembly is arranged to couple power with another one of the two element isolators of one of the at least one inverted-switch-triad-assembly; and

(M+1) components for a respective pair of (M+1)-for-M redundant switches, wherein first input/output ports of the (M+1) components are coupled to a first one of the respective pair of (M+1)-for-M redundant switches and second input/output ports of the (M+1) components are coupled to a second one of the respective pair of (M+1)-for-M redundant switches, wherein the first switch-triad-assembly, the second switch-triad-assembly, and the at least one inverted-switch-triad-assembly are able to route a path through the (M+1)-for-M redundant switch node when a component in the (M+1) components associated with a respective pair of (M+1)-for-M redundant switches has failed.

12. The (M+1)-for-M redundant switch node, of claim **11**, further comprising:

a waveguide structure in which the first switch-triad-assembly, the second switch-triad-assembly and the at least one inverted-switch-triad-assembly are positioned.

13. The (M+1)-for-M redundant switch node, of claim **11**, wherein the at least one inverted-switch-triad-assembly is a positive integral number K of inverted-switch-triad-assemblies, where K is two or more, the (M+1)-for-M redundant switch further comprising:

a plurality of (K−1) sandwiched switch-triad-assemblies, wherein a (K−1) sandwiched switch-triad-assembly includes a fourth switching element circulator and two element isolators, and wherein the plurality of (K−1) sandwiched switch-triad-assemblies are alternately interposed between the K inverted-switch-triad-assemblies,

wherein the element isolators of the plurality of (K−1) sandwiched switch-triad-assemblies are arranged to couple power with the element isolators of the K inverted-switch-triad-assemblies,

wherein the plurality of fourth switching element circulators in the respective plurality of (K−1) sandwiched switch-triad-assemblies include a respective plurality of port legs in a respective plurality of additional input/output ports, and wherein two element isolators in the respective plurality of (K−1) sandwiched switch-triad-assemblies are loaded.

14. The (M+1)-for-M redundant switch node of claim **13**, wherein de minimus gaps are provided between legs of the element isolators of the (K−1) sandwiched switch-triad-assemblies adjacent to the respective legs of the element isolators of the K inverted-switch-triad-assemblies.

15. The (M+1)-for-M redundant switch node of claim **11**, wherein a de minimus gap is provided between a leg of one of the two element isolators of the first switch-triad-assembly and a leg of one of the two element isolators of one of the K inverted-switch-triad-assemblies,

wherein a de minimus gap is provided between a leg of one of the two element isolators of the second switch-triad-assembly and a leg of one of the two element isolators of one of the K inverted-switch-triad-assemblies, and

wherein for at least one of: the first switch-triad-assembly; the second switch-triad-assembly; and the at least one inverted-switch-triad-assembly, a de minimus gap is provided between a leg of the two element isolators and a leg of the switching element circulator.

16. The (M+1)-for-M redundant switch node of claim **11**, wherein at least one leg of at least one of the two element isolators of the first switch-triad-assembly, the second switch-triad-assembly, and the at least one inverted-switch-triad-assembly is at least one loaded leg.

17. The (M+1)-for-M redundant switch node of claim **11**, wherein a continuous junction having no gap is provided between a leg of one of the two element isolators of the first switch-triad-assembly and a leg of one of the two element isolators;

wherein a continuous junction having no gap is provided between a leg of one of the two element isolators of the second switch-triad-assembly and a leg of one of the two element isolators; and

wherein for at least one of: the first switch-triad-assembly; the second switch-triad-assembly; and the at least one inverted-switch-triad-assembly, a continuous junction having no gap is provided between a leg of the two element isolators and a leg of the switching element circulator.

18. The (M+1)-for-M redundant switch node of claim **11**, wherein the element isolators are switching element circulators controlled to circulate electromagnetic fields in one direction until a failure requires at least one switching element circulator to circulate electromagnetic fields in an opposite direction.

19. A 3-for-2 redundant switch, comprising:

a triad-assembly including a first non-switching element isolator, a second non-switching element isolator, and a third non-switching element isolator, wherein the first non-switching element isolator has a loaded leg, the second non-switching element isolator has a first port leg, and the third non-switching element isolator has a second port leg; and

a switch-penta-assembly including a first switching element circulator, a second switching element circulator, a third switching element circulator, a fourth switching element circulator, and a fifth switching element circulator; and

wherein the first and second switching element circulators are coupled to a respective one of the second and third non-switching element isolators, and the other three of the five switching element circulators have port legs.

20. The 3-for-2 redundant switch of claim **19**,

wherein a de minimus gap is provided between adjacent legs of the first and second non-switching element isolators,

wherein a de minimus gap is provided between adjacent legs of the first and third non-switching element isolators,

wherein a de minimus gap is provided between adjacent legs of the first switching element circulator and the third switching element circulator,

wherein a de minimus gap is provided between adjacent legs of the first switching element circulator and the fourth switching element circulator,

wherein a de minimus gap is provided between adjacent legs of the second switching element circulator and the fourth switching element circulator,

wherein a de minimus gap is provided between adjacent legs of the second switching element circulator and the fifth switching element circulator,

wherein a de minimus gap is provided between adjacent legs of the second non-switching element isolator and the first switching element circulator, and

wherein a de minimus gap is provided between adjacent legs of the third non-switching element isolator and the second switching element circulator.

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